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DISCOVERY

Development of depleted oil reservoir for gas storage to forestall gas flaring in Niger Delta region, Nigeria

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Gas flaring is one of the major problems associated with the discovery of crude oil in Delta Region of Nigeria. The government efforts to stop gas flaring through implementation of regulations and decrees have not successful as a result of lack of sufficient storage capacity. In order to solve this lingering problem, the study developed depleted underground gas storage for storing large volume of gas. The study makes use of geological information and production history of a depleted oil reservoir in OSO well, Akwa Ibom State. The data collected were used in the computation of the total storage capacity and the determination of gas losses using "C#" programming language. The results revealed that the total storage capacity of the reservoir was estimated to be 488.32Bscf and the working gas was estimated to be 244.16Bscf of the total storage capacity. Meanwhile, the quantity of gas loss when the pressure dropped from 3424.7psia to 3294.7psia was estimated to be 54.57MMscf. Therefore, the well is suitable to store gas across the Niger Delta Area of Nigeria and put an end to gas flaring across the region.

INTRODUCTION

Nigeria is one of the top holders of world oil and gas reserves, which has attracted both multi-national and indigenous companies producing from the wealth of the nation's oil and gas reserve[1]. However, there has been little or no consideration to the environmental impact of the oil and gas production on the host community as a result of continuous burning and flaring of natural gas[2], [3], [24-26]. Many scholars have studied the impact of gas flaring on the host community. Weli and Itam[4] investigated the impact of crude oil storage tank emissions and gas flaring on air/rainwater quality and weather conditions on Bonny Industrial Island, Nigeria. Ubani and Onyejekwe[5] evaluated the environmental impact analyses of gas flaring in the Niger Delta Region of Nigeria. Ajugwo[6] reported the negative effects of gas flaring in Nigeria. Ito and Ugbome[7] focused their study on the impact of gas flaring on biodiversity in Niger Delta, Nigeria. The continuous burning and flaring of natural gas has polluted the atmosphere with the depletion of the ozone layer and emission of greenhouse gases (GHG)[8], [9]. Okafor and Aniche[10] estimated that the global associated gas flaring as at 2016 was estimated to be over 150 billion cubic meters while in Nigeria alone, gas flaring amounts to about 23 billion cubic meters was flared, constituting over 13 percent of global gas flaring.

The Nigerian government has continued to express its displeasure to gas flaring by making laws that can prohibit gas flaring by oil producer in the country since 1969 up to date [11], [12]. Despite the passage of most of these laws and regulations, gas flaring still persists with oil companies in the country repeatedly flouting Nigerian legislative deadlines, and paying meager fines for breaking the law. This has so far showed the lack of strong will by the government to enforce the law of zero gas flaring by oil companies operating in the country[13], [14]. Also, the World Bank through his founding member Global Gas Flaring Reduction Partnership (GGFR) has directed all the oil producing countries to end gas flaring latest by the year 2030[15]. In order to achieve this vision, there are global responses to gas flaring to partner with oil producing countries for provision of underground gas storage and other facilities that is a viable solution to stop gas flaring across the word [15], [16].

Franco [17] reported that Canada and United States of America were the first two countries to realize the economic importance and technical possibility of storing natural gas in natural reservoirs in 1915 and 1916 respectively. The development of gas storage spread considerably as many countries discovered gas production fields in areas distant from where the gas is to be used especially with the development of importation from one country to another. Cornot-Gandolphe[18] reported that as at the end of 2016, there were 672 underground gas storage (UGS) facilities in operation in the world, representing a working gas capacity of 424 billion cubic meters (bcm). The report enumerated that North America concentrates more than two thirds of the sites, with 392 active storages in the US, and 62 in Canada, a combined working capacity of 160 bcm (38% of the world total).

Geoffroy[19] proposed an increase in global underground gas storage capacity from 413 bcm in 2015 to between 547 bcm and 640 bcm in 2035which required between €100 billion to €170 billion Investment. Depleted oil/gas fields is ranked the predominant type of underground gas storage with over 498 facilities in the world, depleted fields

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Table 1 Reservoir and fluid data for inventory verification of the reservoir

Data	Value	Unit
Cumulative oil produced, N_P	1165420	MMstb
Oil formation volume factor, Bo	1.77093	rb/stb
Gas formation volume factor, B_g	0.000088	Rcf/scf
Initial pressure, P_i	3410	Psig
Initial compressibility factor at P_i, Z_i	0.865	-
New pressure, P	3280	Psig
Compressibility factor at P, Z	0.874	-

Table 2 Reservoir and fluid data for quantity of gas loss in the reservoir

Data	Value	Unit
Initial pressure, P_1	3410	Psig
Initial temperature, T_1	127	^{0}F
Initial compressibility factor, Z_1	0.865	-
New Pressure, P_2	3280	Psig
New temperature, T_2	122	^{0}F
New compressibility factor, Z_2	0.874	-
Area of reservoir, A	54	Acres
Thickness of reservoir, t	81	Ft
Porosity, Ø	0.29	%
Permeability, k	500	Md

represent 74% of the total number of sites and 80% of working gas volumes[19]. Despite of the availability of depleted oil and gas fields across the Niger Delta Region of Nigeria, Nigeria has no record of any underground gas storage site. Based on this fact, the study reviewed the problems of gas flaring and developed a depleted oil reservoir to forestall gas flaring using OSO well in Niger Delta Region of Nigeria.

MATERIALS AND METHODS

Description of the Study Area

Nigeria has a coastal line of approximately 85km towards the Atlantic Ocean lying between the latitude 4°15' to 4°50' and the longitude 5°25' to 7°37' with a land mass of about 28000sq/km area within the coastal region. In which the surface area of the continental shelf is 46300sq/km. The coastal areas consist of freshwater swamps, mangrove swamp, beach ridges, sand bars, lagoon marshes and tidal channels. Nigeria has a total land mass of 923,768sq/km; 918,768sq/km being terrestrial land and 13000 sq/km being aquatic [20]. The coastal area is humid with a mean average temperature of 24-32°C and coastal area has an average annual rainfall ranging between 1,500-4,000m [21]. Nigeria produces her petroleum from mainly the Niger Delta region of the country. The Niger Delta consists of mainly nine (9) states of the thirty-six states (36) in Nigeria; Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo and Rivers state. The Niger Delta region of Nigeria has the major producing oil fields in the country, and represents a special consideration for the production of oil and gas region of the country.

Data Collection

This study depends solely on the secondary data collected from a depleted OSO well oil reservoir located in Akwa-Ibom State, Nigeria. The production and pressure data of the depleted OSO well oil reservoir were analyzed for inventory verification and retention against migration. These data are presented in Tables 1 and 2 respectively.

Data Analysis

"C Sharp (C #) software programme was developed to analyze the data in Tables 1 and 2 using the derived volumetric Equations1-8. The software programme was used to obtain the total volume of gas that can be injected into the reservoir, the total storage capacity and the quantity of gas loss.

(a) Verification of inventory (storage capacity) of the reservoir

According to Anyadiegwu and Anyanwu[22] the verification of inventory (capacity) of a depleted oil reservoir may be found as follows: The total storage capacity is given by Equation 1.

$$V_t = G_p / [1 - (P * Z_i)/(P_i * Z)] \qquad (1)$$

$$\text{And} \qquad G_p = N_p * B_o / B_g$$

Where; N_p is cumulative oil production, stb; B_0 is formation volume factor, rb/stb; $B_g$is gas formation volume factor, rcf/scf; P_i is initial reservoir pressure, psia; P is new pressure, psia; $Z_i$is initial compressibility factor; Z is compressibility factor at P; $G_p$is gas produced, scf; T is reservoir temperature, ^{0}R; $V_t$is total storage capacity, scf.

In estimating the storage capacity of the reservoir, pressure in (psig) is converted to pressure in (psia) using Equation 2;

$$P_{(psia)} = P_{(psig)} + 14.7 \qquad (2)$$

The temperature in Fahrenheit (^{0}F) is also converted to degrees Rankine (^{0}R) using Equation 3.

$$^oR = {}^\circ\mathrm{F} + 460 \qquad (3)$$

Hence, V_t represent the total volume of gas to replace the oil produced from the reservoir, also known as the total storage capacity of the reservoir for underground gas storage.

Also, the working gas capacity of a depleted reservoir is 50% of the total storage capacity, while the remaining 50% is the cushion gas.

Therefore, the working gas capacity is calculated from Equation 4.

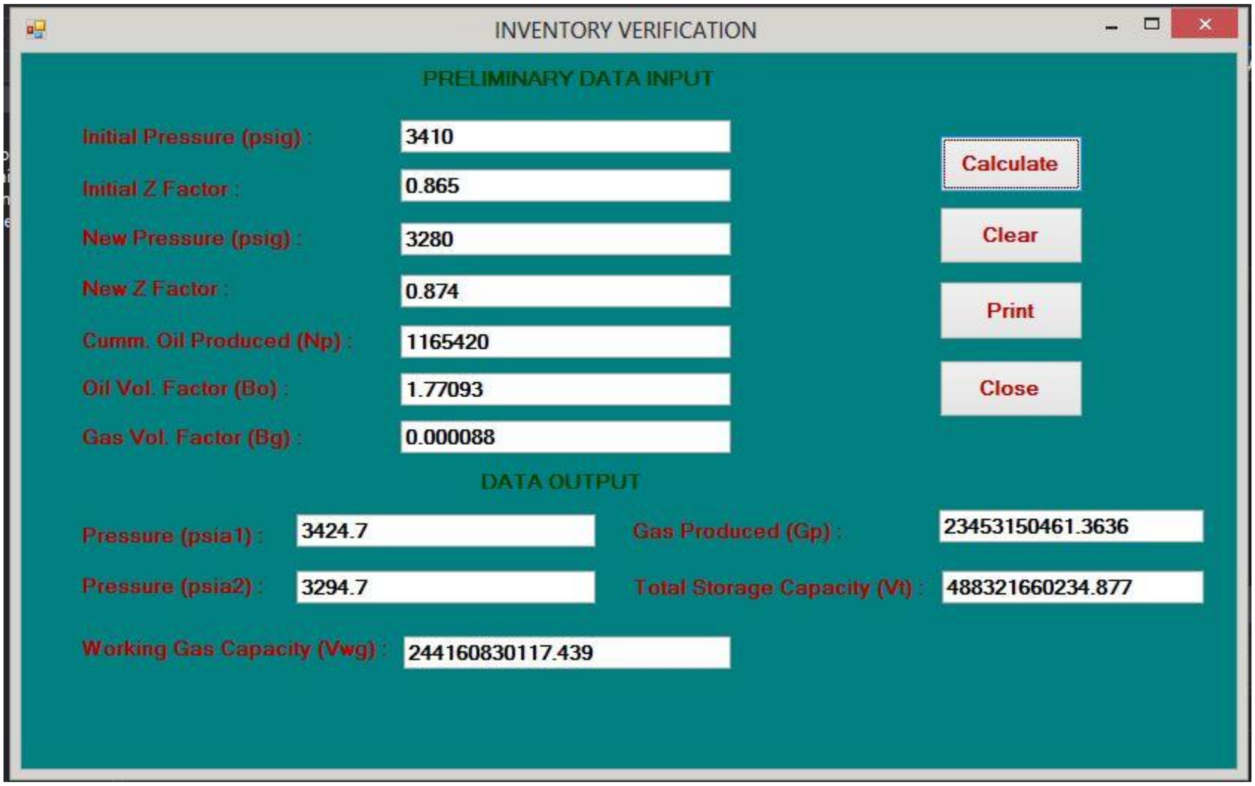

Figure 1 Total Storage Capacity of the Reservoir

$$V_{wg} = (50 * V_t)/100 \qquad (4)$$

Where, V_{wg}= working gas capacity, scf

(b) Retention against migration and quantity of gas loss

According to Muonagor & Anyadiegwu[23], the quantity of gas loss from a gas storage system is estimated as shown in Equation 5:

$$G = 35.3021 * P_V * [\,{}^{P_1}/_{(T_1 * Z_1)} - {}^{P_2}/_{(T_2 * Z_2)}] \qquad (5)$$

Where: G is Estimated Quantity of Gas Loss scf; P_1 is Initial Pressure of the Storage System, psia; $T_1$is Initial Temperature of the Storage System, ^{0}R;Z_1 is Initial Compressibility Factor of the Gas in the Storage System;$P_2$is New Pressure of the Storage System, psia; T_2 is New Temperature of the Storage System, ^{0}R; $Z_2$is New Compressibility Factor of the Gas in the Storage System; P_V is Pore Volume of the reservoir, scf.

In estimating the quantity of gas loss from the reservoir, pressure in (psig) is converted to pressure in (psia) using Equation 6:

$$P_{(psia)} = P_{(psig)} + 14.7 \qquad (6)$$

The temperature in Fahrenheit (^{0}F) is also converted to degrees Rankine (^{0}R) using Equation 7

$$^{o}R = {}^{\circ}F + 460 \qquad (7)$$

According to Muonagor and Anyadiegwu[23]**,** V is expressed as the pore volume of the reservoir in scf using the Equation 8.

$$P_V = (43560 * A * t * Porosity \qquad (8)$$

RESULT AND DISCUSSION

Verification of Inventory (Storage Capacity)

The value of the initial pressure, initial Z factor, new pressure, new Z factor, cumulative oil produced, oil formation volume factor, and the gas formation volume factor was given in Table 1. These values were inputted into the programme to obtain the total storage capacity (TSC) of the reservoir as shown in Fig.1.

The total storage capacity of a reservoir for gas storage is the maximum quantity of gas that can be stored in the reservoir. Fig.1 shows that the total storage capacity of the depleted reservoir is estimated to be 488.32 Bscf which is suitable to store gas from various oil producing fields across the Niger Delta Area of Nigeria and put an end to gas flaring across the region. Also, working gas, which is the quantity of gas that could be recovered practically from the total gas capacity of the reservoir, was estimated to be 244.16 Bscf of the total storage capacity (Fig.1). In the depleted underground gas storage, the working gas capacity is 50% of the total storage capacity while the remaining 50% represents the base or cushion gas, which is the volume of gas that is immobilized in the reservoir for the storage to work efficiently at the maximum possible performance.

The development of depleted underground gas storage can store gas from various oil fields by field clustering, in which pipelines are interconnected from each nearest field to another to make transmission more economical. The natural gas from various oil producing fields can then be assembled daily to the reservoir by metering facilities that can regulate the rate of injection of natural gas into the reservoir which automatically eliminate gas flaring. Consequently, development of depleted underground gas storage will ensure an economic use of gas in the country; safe the environment from the release of poisonous gasses and invariably eliminating the risk to the health of the populace.

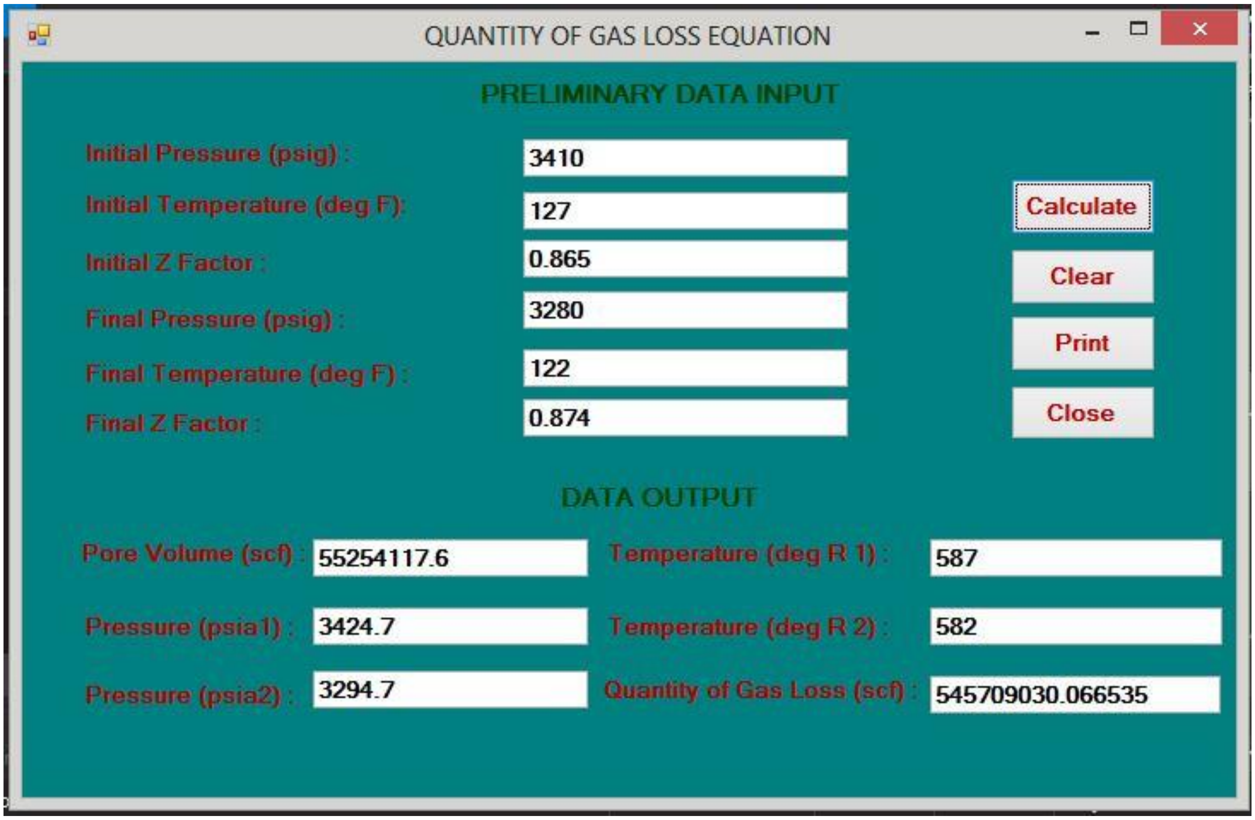

Figure 2 Quantity of Gas Loss at A Pressure Drop from 3410 psig to 3280 psig

Retention against Migration and Quantity of Gas Loss

Depleted oil reservoir for underground storage can store natural gas for quite a long period of years and recovered when needed without gas leakage or loss if properly developed and maintained. On the other hand, the quantity of gas that might be lost if not developed as appropriate can be estimated by inputting the values in Table 2 into Fig.2. The quantity of gas loss in the reservoir when the pressure dropped from 3410 psig (3424.7 psia) to 3280 psig (3294.7 psia) is estimated to be 54.57 MMscf. This represents a minimum loss of gas which might be due to leakages from the depleted oil reservoir casing and cementation as a result of deterioration, or the possibility of water encroachment which can reduce the bottom reservoir pressure. Hence, it is important to check for leakages in the reservoir casing and cementation to seal off as appropriate. Moreover, there is a need to check for the possibility of water encroachment in the reservoir and correct by maintaining the discovery reservoir pressure to prevent the possible loss of gas in the reservoir.

CONCLUSION

This study developed depleted underground gas storage in Niger Delta Region in order to eradicate gas flaring. Gas flaring is the wasteful burning of gas associated with oil during production to the atmosphere. Hence, it is a waste of energy resources and causes the release of poisonous chemicals to the atmosphere, bringing about intoxication of the atmosphere and invariably climate change. Gas flaring persists in Nigeria mainly because, her oil producing fields lack enough storage capacity to store gas associated with oil produced. In order to eradicate this problem, the study developed depleted underground gas storage. The development of depleted underground gas storage shows that its inventory (total storage capacity) is 488.32 Bscf and the test for the leakage of the reservoir for a drop in pressure from the initial pressure of 3410 psig to 3280 psig showed the amount of gas loss would be 54.57 MMscf. This implies that the developed underground gas storage is suitable to store all the gases released from oil field across the Niger Delta and put an end to gas flaring. The study therefore recommended that government should take the lead to develop depleted underground storage for the oil producing fields and stopped setting deadline dates for gas flaring.

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